Estimation of gillnet selectivity for Atlantic herring (*Clupea harengus harengus* L.) from the west coast of Newfoundland, 1997-2001

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ESTIMATION OF GILLNET SELECTIVITY FOR ATLANTIC HERRING (*Clupea harengus harengus* L.) FROM THE WEST COAST OF NEWFOUNDLAND, 1997-2001

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ABSTRACT

Grégoire, F., and L. Lefebvre. 2003. Estimation of gillnet selectivity for Atlantic herring (*Clupea harengus harengus* L.) from the west coast of Newfoundland, 1997-2001. Can. Ind. Rep. Fish. Aquat. Sci. 272: vii + 22 p.

Atlantic herring (*Clupea harengus harengus* L.) is commercially fished off the west coast of Newfoundland by a large number of fishers using gillnets. Gillnets are a very selective fishing gear, so fishers use different mesh sizes to maximize captures. We calculated gillnet selectivity for three different mesh sizes using catch data from index fishers for the 1997 to 2001 period. The results of this study demonstrate that the probability of capturing larger Atlantic herring increases with mesh size. For example, in 1999, the modal lengths of herring estimated by a normal selectivity model were 38 cm, 39.9 cm, and 41.8 cm for mesh sizes of 63.50 mm, 66.80 mm, and 69.85 mm, respectively. These results also demonstrate that there were changes in the modal lengths and selectivity for a given mesh size over the study period. Finally, a yield per recruit analysis indicates that the best yields would be obtained using nets with the smallest mesh size.

RÉSUMÉ

Grégoire, F., et L. Lefebvre. 2003. Estimation of gillnet selectivity for Atlantic herring (*Clupea harengus harengus* L.) from the west coast of Newfoundland, 1997-2001. Can. Ind. Rep. Fish. Aquat. Sci. 272: vii + 22 p.

Le hareng (*Clupea harengus harengus* L.) de la côte ouest de Terre-Neuve est pêché commercialement par un grand nombre de pêcheurs utilisant le filet maillant. Ce dernier est un engin de pêche très sélectif, ce qui amène les pêcheurs à utiliser des filets de différentes grosseurs de maille pour maximiser les captures. Dans le cadre d'une étude qui s'est déroulée entre 1997 et 2001, la sélectivité des filets maillants a été calculée pour trois grosseurs de maille différentes à partir des prises provenant des pêcheurs repères. Les résultats de cette étude démontrent que les probabilités de capturer du plus gros hareng augmentent avec la grosseur des mailles. Par exemple, en 1999, les longueurs modales des harengs estimées par un modèle normal de sélectivité étaient respectivement de 38 cm, 39.9 cm et 41.8 cm pour des mailles de 63.50 mm, 66.80 mm et 69.85 mm. Les résultats démontrent aussi des changements de longueurs modales et de sélectivité pour une même grosseur de maille au cours de la période d'étude. Finalement, une analyse de rendement par recrue indique que les meilleurs rendements seraient obtenus par l'utilisation des filets ayant les plus petites mailles.

INTRODUCTION

The Atlantic herring (*Clupea harengus harengus* L.) found off the west coast of Newfoundland, in Northwest Atlantic Fisheries Organization (NAFO) division 4R (Figure 1), is fished commercially by a fleet of 16 small (< 65′ / 19.9 m) and 5 large (> 65′ / 19.9 m) seiners and by nearly 800 gillnetters. The latter land about 2 500 t of Atlantic herring a year (catches used for bait are not declared), more than half from unit area 4Ra (Figure 1). Because of the limited market demand for this fishery, Atlantic herring landings by gillnetters represent only 20% of the annual landings in this part of the Gulf of St. Lawrence. However, the importance of this fishery is seen more in the number of fishers that take part than in the quantity of fish landed.

Gillnets are recognized as a very selective type of fishing gear (Hamley 1975; Gulland 1983); for a given mesh size, the range of fish lengths captured is well defined and sometimes very narrow. In addition to mesh size, selectivity may be affected by many other factors, such as the characteristics of the net material (e.g., elasticity, flexibility, visibility), the shape of the fish, their availability, sexual maturity, and even the way the nets are made and used. Mortality and growth calculations for a particular fish stock may be seriously distorted if the samples used for the calculation come from selective fishing gear like gillnets. Conversely, gillnet selectivity may be used as a management tool, to avoid capturing small fish or to maximize yields (Hamley, 1975). Different calculation techniques have been proposed to measure gillnet selectivity. A review of these techniques is presented in Regier and Robson (1966), Hamley (1975), Holst and Moth-Poulsen (1995), and Hovgård and Lassen (2000).

The objective of this study was to measure the selectivity of gillnets used in the Atlantic herring fishery off the west coast of Newfoundland. A secondary objective was to determine the mesh size that produced the best yields.

MATERIAL AND METHODS

Input data

The period covered by this study was from 1997 to 2001. The basic data come from biological samples taken once a week by index fishers in the spring and summer. Three mesh sizes were used by these fishers: 63.50 mm (2 1/2"), 66.80 mm (2 5/8"), and 69.85 mm (2 3/4"). Some fishers used only one mesh size over the whole study period while others changed sizes during the study. In the laboratory, a number of variables, such as length (mm), total weight (g), gonad weight (g), sex, and maturity, were measured for each fish sampled. For each sample, the number of Atlantic herring per length class (cm) was determined then weighted using the weight of the corresponding landings. These numbers were then collated by mesh size and year.

Selectivity estimate

Among the techniques proposed for calculating gillnet selectivity, that of Millar and Holst (1997) was selected for this study. This technique allows log-linear selectivity models (Appendix 1) to be easily fitted to length frequency data. We used the GILLNET software (Holst *et al.*, undated) to fit the most commonly used models. Goodness of fit was measured by deviance, a statistic calculated by this software. Model choice was determined by deviance, the model's simplicity, and the residual distribution. The modal length of herring estimated by the chosen selectivity model was calculated for each mesh size and compared among years.

Yield per recruit analysis

A yield per recruit analysis was done following the Beverton and Holt model (Ricker, 1975) to determine the mesh size that afforded the best yields. Basic inputs required for this analysis are the parameters of growth in length and weight at the age given by the von Bertalanffy model (Ricker, 1975); age at recruitment to the fishery, that is, Beverton and Holt's *tp'* (Ricker, 1975); and the modal lengths of the various selectivity curves. Yields were calculated for a natural mortality (M) of 0.2 and fishing mortalities (F) varying from 0.01 to 0.3.

RESULTS

Atlantic herring samples used for this study were harvested by seven index fishers whose catches were landed in five different fishing communities (Figure 1). The weight of the landings varied between 50 kg and 3 300 kg (Table 1). For all herring measured, lengths varied from 24 to 43 cm (Appendix 2). The most commonly used mesh sizes were 66.80 mm and 69.85 mm. All three mesh sizes were used only in 1999 (Table 2). The length frequency distributions, clustered by mesh size, were unimodal in 1997 and 1998 but bimodal subsequently (Figure 2).

In 2001, the normal model with a proportional spread was used; in other years, the normal model with a fixed spread was chosen (Table 3). For all models, residuals were well distributed and did not show high values for individual fish lengths (Figure 3).

The probability of capturing the largest Atlantic herring increased with mesh size, with higher modal lengths for the biggest mesh size (Figure 4). For example, in 1999, modal lengths were respectively 38 cm, 39.9 cm, and 41.8 cm for mesh sizes of 63.50 mm, 66.80 mm, and 69.85 mm. However, for a given mesh size, selectivity could also vary year to year (Figure 5). For example, for the 69.85 mm mesh size, herring modal length increased from 37.5 cm in 1997 to 48.1 cm in 2000, then fell to 42.7 cm in 2001 (Figure 6). Similar changes were also seen for the 66.80 mm mesh size between 1998 and 2001. Over the years, a constant ratio was observed between the modal lengths associated with these two mesh sizes. Thus, a factor of 1.05 could be used to convert each year's modal length for the 66.80 mm mesh size to the 69.85 mm equivalent.

Yield per recruit analysis shows that the best yields for a given fishing mortality would be achieved with nets having a mesh size of 63.50 mm (Figure 7A). The average age at recruitment would be 1.23 years for 63.50 mm nets, which compares to 2.63 years and 4.42 years for the 66.80 mm and 69.85 mm mesh sizes (Figure 7B).

CONCLUSION

The main point of this study is changes in selectivity that have been observed over the years for nets having the same mesh size. These changes may have come about because of a dominant year-class in the population. Thus, the annual growth of one of these classes would be responsible for the gradual displacement of the modal length of a selectivity curve toward higher values. In this case, the samples of Atlantic herring were characterized by two dominant year-classes, that of 1990 seen in the data between 1997 and 2000, and 1994 between 1999 and 2001 (Figure 2). For fish stocks in which certain year-classes are dominant, studies of gillnet selectivity need to be conducted over a number of years to take this into account. The same is true for the yield per recruit analysis, the results of which are directly linked to the selectivity characteristics of the fishing gear.

No study of gillnet selectivity would be complete without the simultaneous use of nets with different mesh sizes. In this case, Atlantic herring index fishers used only groups of nets with the same mesh size. In the framework of an exploratory fishery, the use of meshes smaller than those used in the commercial fishery would allow the abundance of smaller fish (recruits) to be measured, even though these would normally only be caught after several more years.

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Table 1. Description of the data on landings (t) and mesh sizes (mm-in.) used in the Newfoundland west coast Atlantic herring selectivity study for the 1997-2001 period.

YEAR	CFV*	LANDING PORT**	MESH (mm - in.)	DAY OF THE YEAR	LANDING (kg)
1997	1	Robinson	66.80 - 2 5/8	124	70
				129	70
			Total		***140***
1997	2	Fishels	66.80 - 2 5/8	128	300
				133	250
			Total		***550***
1997	3	Sandy Point	69.85 - 2 3/4	119	500
				125	200
				133	300
				141	75
				156	100
				161	100
			Total		***1 275***
1997	4	Sandy Point	63.50 - 2 1/2	122	600
				126	650
				136	700
				139	750
				150	200
				155	100
			Total		***3 000***
1997	4	Sandy Point	66.80 - 2 5/8	160	450
				167	600
			Total		***1 050***
1997	5	Black Duck Brook	69.85 - 2 3/4	NA	300
				127	1 800
				134	1 200
			Total		***3 300***
1997	6	Lourdes	63.50 - 2 1/2	122	275
				125	600
				132	200
				148	100
				152	150
				162	23
			Total		***1 348***
1998	7	Fishels	66.80 - 2 5/8	135	60
				140	500
				145	80

Table 1. (Continued).

YEAR	CFV*	LANDING PORT**	MESH (mm - in.)	DAY OF THE YEAR	LANDING (kg)
1998	3	Sandy Point	69.85 - 2 3/4	119	400
				124	500
			Total		***900***
1998	4	Sandy Point	66.80 - 2 5/8	107	100
				113	325
				122	250
				125	720
				131	300
			Total		***1 695***
1998	6	Lourdes	66.80 - 2 5/8	127	35
				131	100
				138	40
				146	34
			Total		***209***
1999	1	Robinson	66.80 - 2 5/8	144	50
			Total		***50***
1999	7	Fishels	66.80 - 2 5/8	141	70
				144	150
				151	90
				160	120
				168	215
				176	200
				180	325
				186	400
			Total		***1 570***
1999	3	Sandy Point	69.85 - 2 3/4	121	150
				123	300
				130	350
				140	90
				144	150
			Total		***1 040***
1999	4	Sandy Point	63.50 - 2 1/2	114	150
				118	600
				123	200
				130	900
				137	400
			Total		***2 250***
1999	6	Lourdes	66.80 - 2 5/8	110	320
			Total		***320***

Table 1. (Continued).

YEAR	CFV*	LANDING PORT**	MESH (mm - in.)	DAY OF THE YEAR	LANDING (kg)
1999	6	Lourdes	63.50 - 2 1/2	125	70
				129	200
				136	80
				143	100
				150	100
			Total		***550***
2000	1	Robinson	66.80 - 2 5/8	131	100
				139	45
				143	100
			Total		***245***
2000	7	Fishels	66.80 - 2 5/8	123	450
				132	1 000
				137	1 000
				146	140
				164	350
				183	130
			Total		***2 940***
2000	3	Sandy Point	69.85 - 2 3/4	115	150
				122	300
			Total		***450***
2000	3	Sandy Point	69.85 - 2 3/4	132	100
				141	175
			Total		***275***
2000	6	Lourdes	63.50 - 2 1/2	122	350
					350
2000	6	Lourdes	66.80 - 2 5/8	136	330
				143	400
				151	125
				157	85
				164	75
				171	60
			Total		***1 775***
2001	1	Robinson	66.80 - 2 5/8	125	60
				143	150
			Total		***210***
2001	7	Fishels	66.80 - 2 5/8	135	800
				142	1 000
				147	1 000
			Total		***2 800***

Table 1. (Continued).

YEAR	CFV*	LANDING PORT**	MESH (mm - in.)	DAY OF THE YEAR	LANDING (kg)
2001	3	Sandy Point	69.85 - 2 3/4	114	300
				121	650
				133	400
			Total		***1 350***
2001	6	Lourdes	63.50 - 2 1/2	123	500
				130	460
				138	315
			Total		***1 275***
2001	6	Lourdes	66.80 - 2 5/8	145	80
				148	200
				155	120
				162	170
				170	100
				178	80
			Total		***750***

* Commercial Fishing Vessel

** See Figure 1

Table 2. Number of fish by length (cm) and mesh size (mm-in.) used in the Newfoundland west coast Atlantic herring selectivity study for the 1997-2001 period.

LENGTH	1997		1998		1999		
(cm)	63.50 mm - 2 1/2 in.	69.85 mm - 2 3/4 in.	66.80 mm - 2 5/8 in.	69.85 mm - 2 3/4 in.	63.50 mm - 2 1/2 in.	66.80 mm - 2 5/8 in.	69.85 mm - 2 3/4 in.
24	0	0	0	0	0	11	0
25	0	0	0	0	0	0	0
26	0	0	0	0	0	12	0
27	0	0	0	0	0	24	0
28	0	0	0	0	170	41	0
29	29	0	0	0	655	175	19
30	39	6	0	0	1 273	288	77
31	401	191	136	0	834	497	27
32	1 459	299	416	68	442	456	63
33	2 380	1 269	1 379	186	591	506	239
34	2 070	1 306	1 629	432	1 358	589	517
35	1 327	1 404	1 718	348	1 720	742	691
36	821	1 044	868	318	1 585	504	583
37	558	698	660	447	671	396	394
38	391	688	610	303	257	336	293
39	384	338	223	204	217	121	147
40	12	145	89	132	102	124	63
41	0	12	16	0	5	93	9
42	0	0	0	23	0	11	0
43	0	0	0	0	0	0	0

LENGTH	2000		2001	
(cm)	66.80 mm - 2 5/8 in.	69.85 mm - 2 3/4 in.	66.80 mm - 2 5/8 in.	69.85 mm - 2 3/4 in.
24	0	0	0	0
25	0	0	0	0
26	41	0	0	0
27	0	0	0	0
28	177	0	0	0
29	291	0	4	0
30	793	78	0	6
31	1 857	152	95	191
32	2 011	218	212	299
33	1 691	239	615	1 269
34	1 084	131	840	1 306
35	1 194	254	686	1 404
36	1 330	350	463	1 044
37	1 799	368	424	698
38	800	168	328	688
39	476	145	73	338
40	180	35	116	145
41	51	28	0	12
42	8	10	0	0
43	21	0	0	0

Table 3. Parameters and deviances of the models tested in the Newfoundland west coast Atlantic herring selectivity study for the 1997-2001 period.

YEAR	MODEL*	PARAMETER *	ESTIMATED t VALUE	DEGREES OF FREEDOM (d.f.)	PROBABILITY (p)	DEVIANCE **
1997	Normal	k_1	13.73	11	0.05	45.12
	(proportional spread)	k_2	1.42		0.39	
	Normal (fixed spread)	k	13.65	11	0.05	**40.99*** **
		s	3.76		0.17	
	Gamma	k	0.15	11	0.90	40.99
		a	91.85		0.01	
	Lognormal	u_1	3.54	11	---	39.30
		s	0.11		---	
1998	Normal	k_1	14.59	10	0.04	17.71
	(proportional spread)	k_2	0.83		0.56	
	Normal (fixed spread)	k	14.65	10	0.04	**17.61*** **
		s	2.45		0.25	
	Gamma	k	0.06	10	0.96	17.61
		a	258.86		0.00	
	Lognormal	u_1	3.66	10	0.17	17.77
		s	0.07		0.96	
1999	Normal	k_1	15.07	34	0.04	157.35
	(proportional spread)	k_2	1.39		0.40	
	Normal (fixed spread)	k	15.20	34	0.04	**152.15*** **
		s	4.15		0.15	
	Gamma	k	0.17	34	0.89	151.04
		a	91.72		0.01	
	Lognormal	u_1	3.66	34	---	148.91
		s	0.11		---	

Table 3. (Continued).

YEAR	MODEL*	PARAMETER*	ESTIMATED t VALUE	DEGREES OF FREEDOM (d.f.)	PROBABILITY (p)	DEVIANCE **
2000	Normal	k_1	16.48	15	0.04	18.59
	(proportional spread)	k_2	1.05		0.48	
	Normal (fixed spread)	k	17.51	15	0.04	**15.59*** **
		s	3.78		0.16	
	Gamma	k	0.11	15	0.93	15.59
		a	156.41		0.00	
	Lognormal	u_1	3.88	15	---	14.70
		s	0.09		---	
2001	Normal	k_1	15.51	11	0.04	**29.08*** **
	(proportional spread)	k_2	1.20		0.44	
	Normal (fixed spread)	k	16.27	11	0.04	31.72
		s	4.17		0.15	
	Gamma	k	0.15	11	0.91	31.72
		a	111.31		0.01	
	Lognormal****	u_1	---	---	---	---
		s	---	---	---	---

* See Appendix 1

** See the text

*** Selected model

**** No convergence

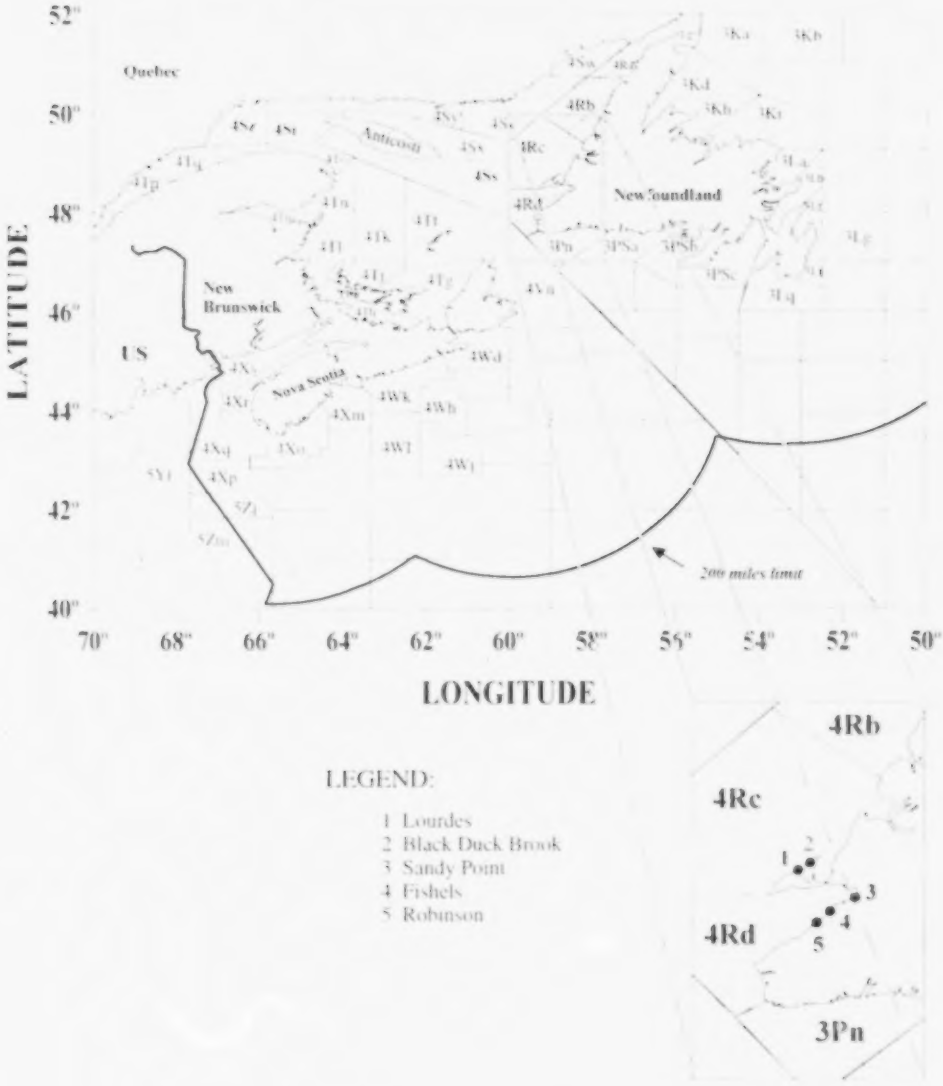
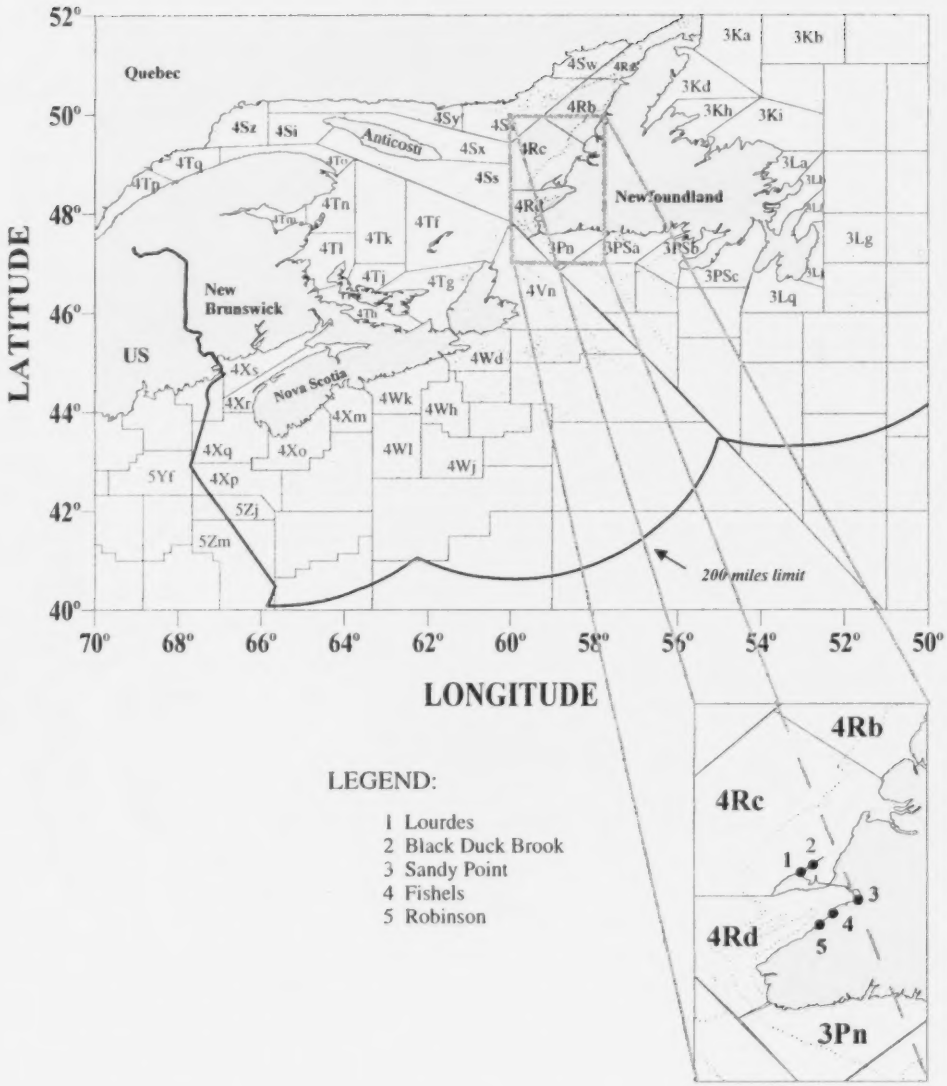


Figure 1. Map of the principal NAFO divisions, subdivisions, and unit areas of Eastern Canada (Division 4R is represented by the shaded area; fishing communities involved in the selectivity study are also indicated).



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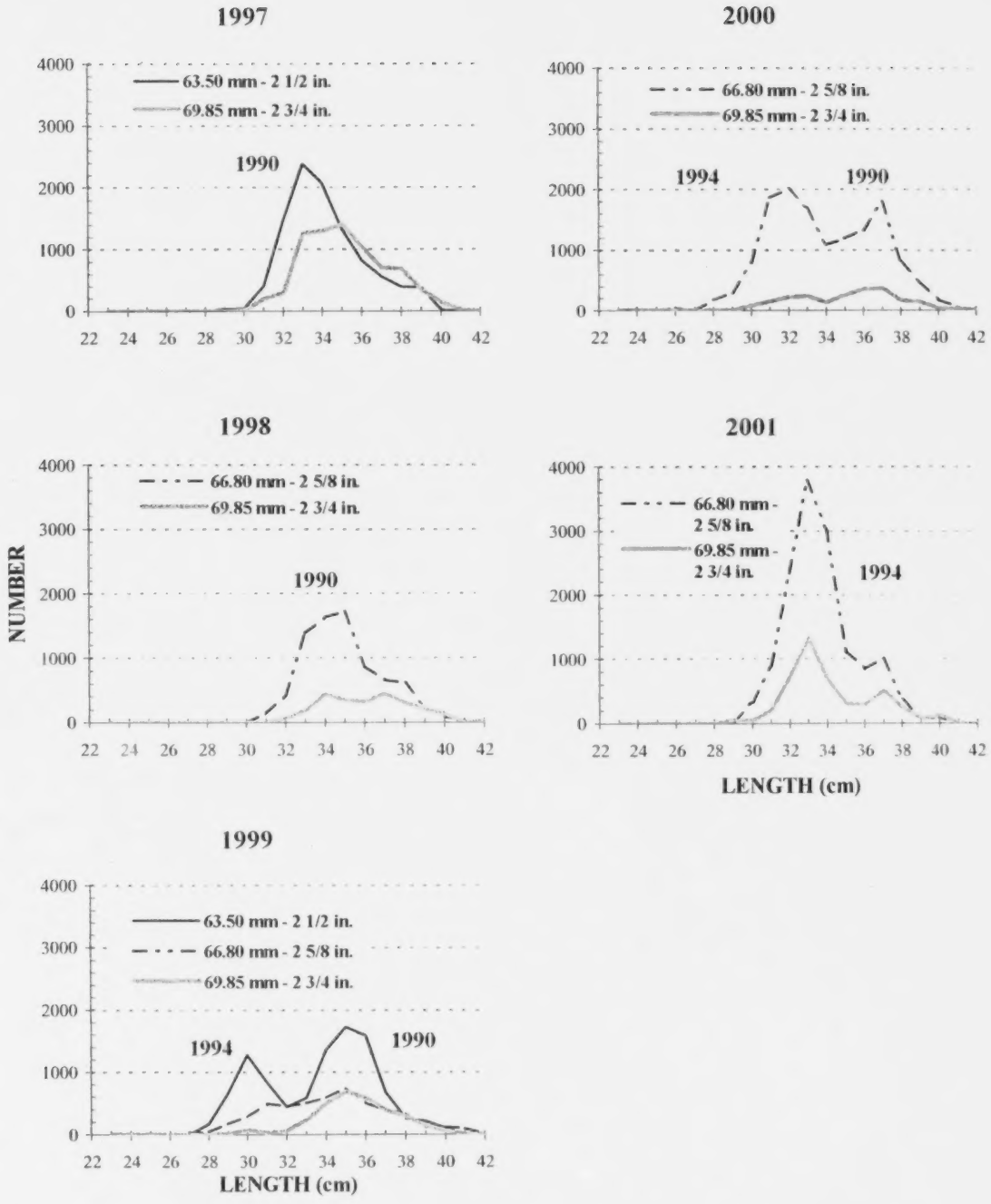

Figure 2. Number of fish by length (cm) and mesh size (mm-in.) used in the Newfoundland west coast Atlantic herring selectivity study for the 1997-2001 period. The dates near the curves refer to the strong year-classes.

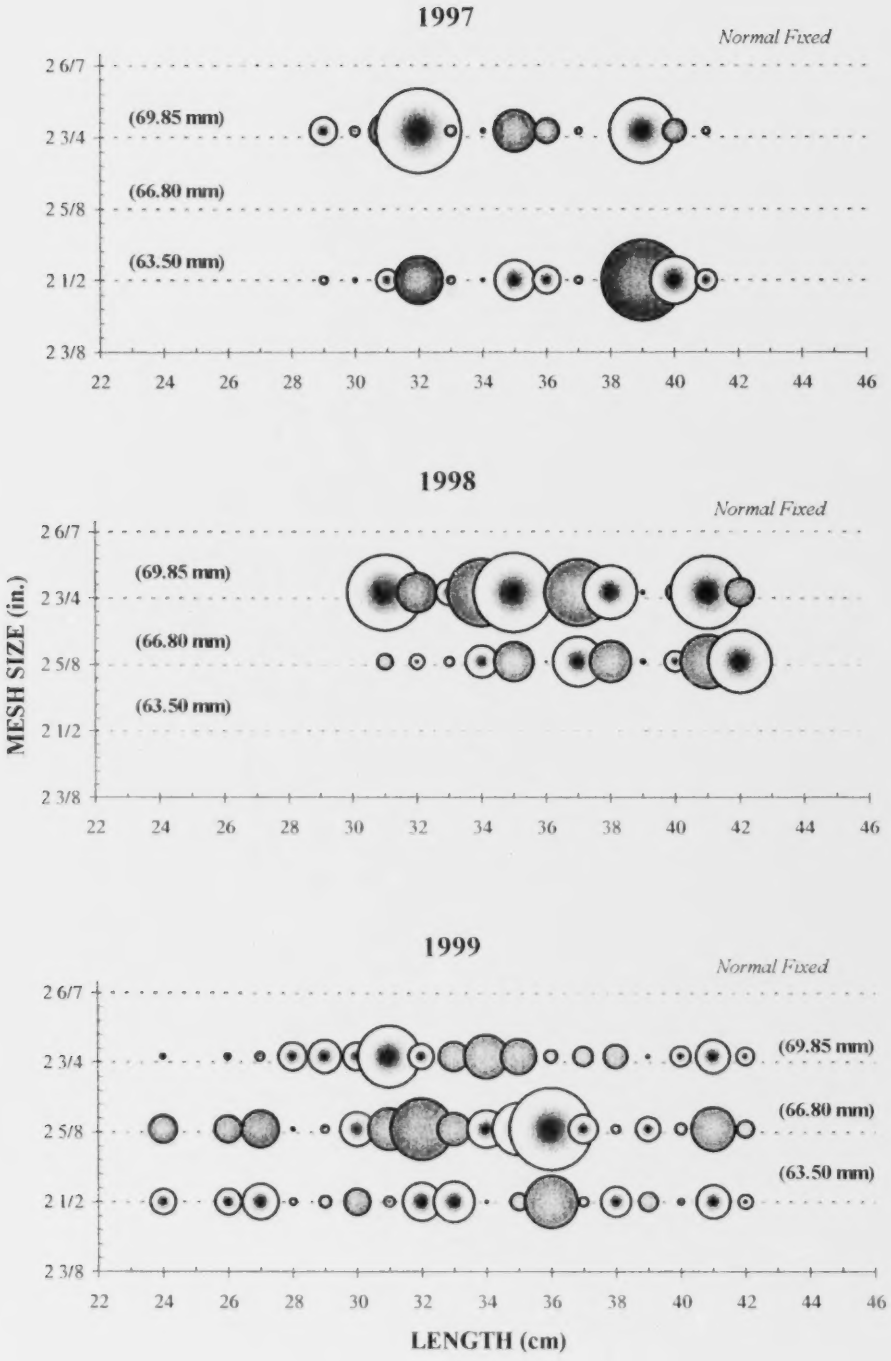

Figure 3. Residuals of the models used to calculate gillnet selectivity of Newfoundland west coast Atlantic herring for the 1997-2001 period (solid symbols indicate positive values, light symbols indicate negative values, bubble diameter is proportional to magnitude).

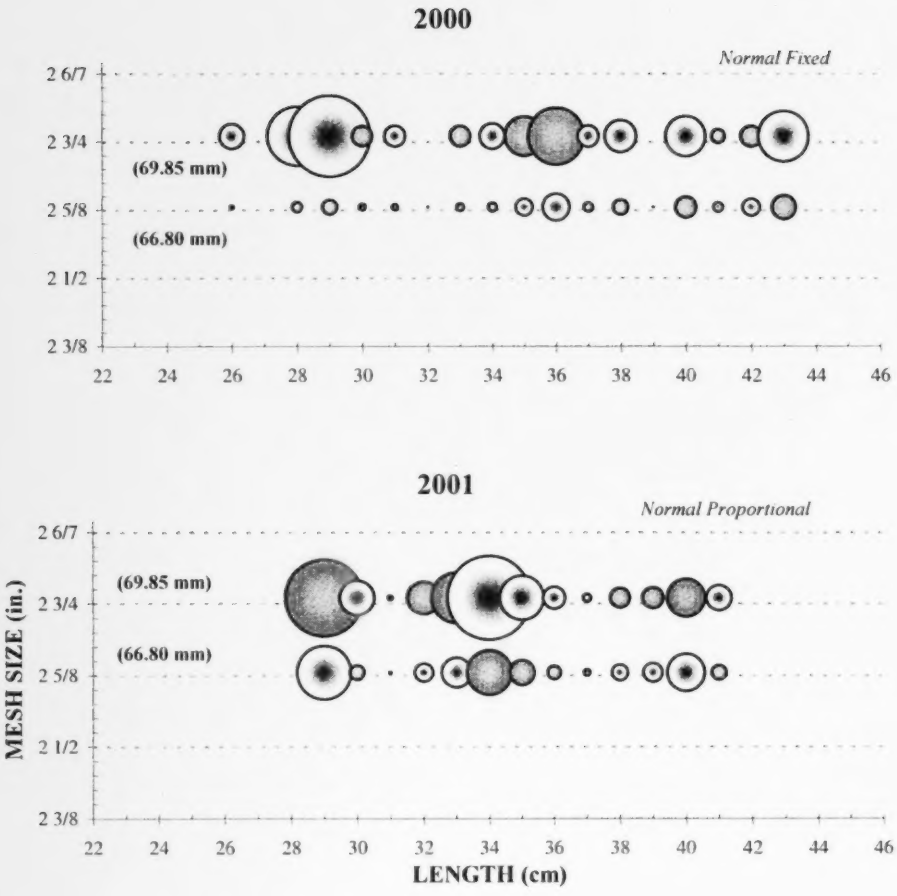

Figure 3. (Continued).

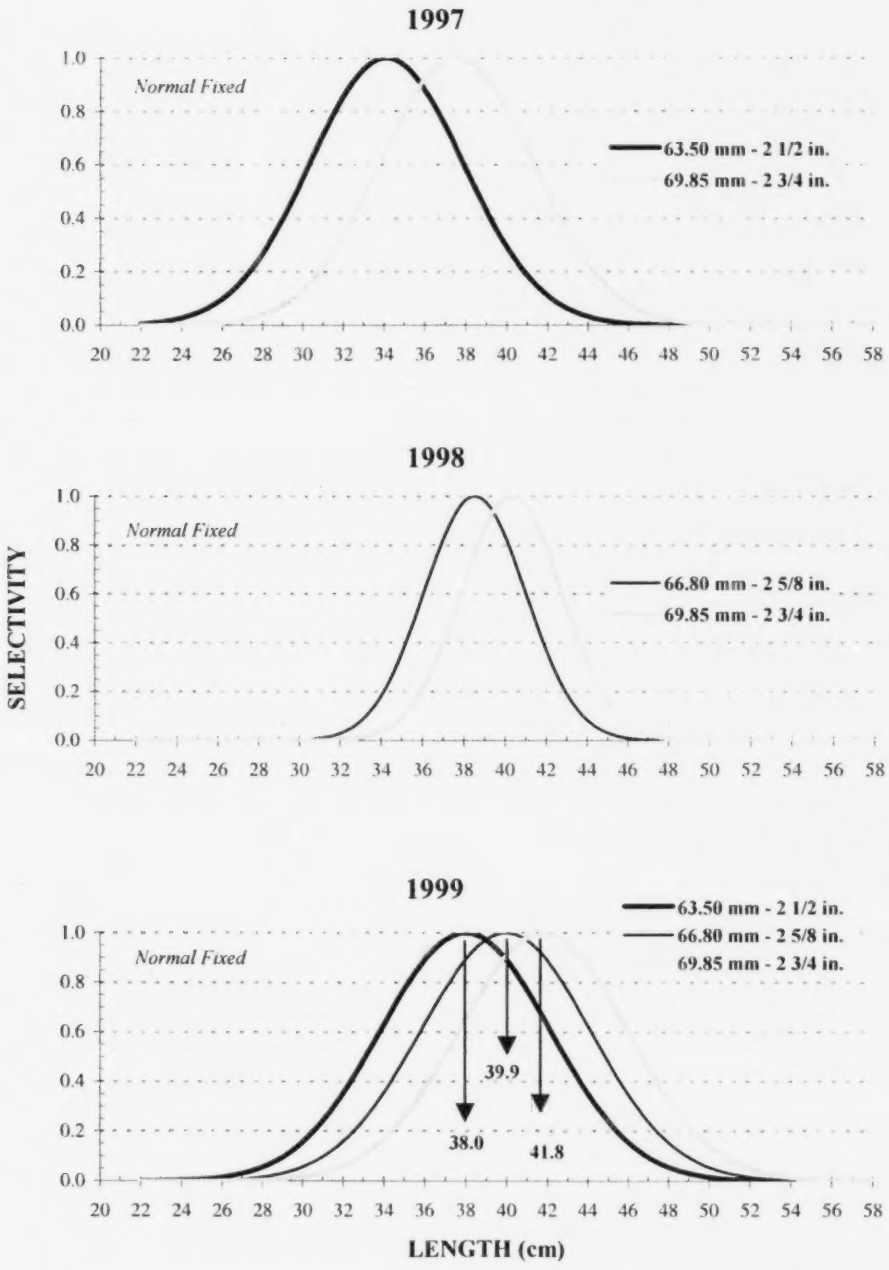

Figure 4. Selectivity curves calculated by year and mesh size for Newfoundland west coast Atlantic herring for the 1997-2001 period (the arrows in 1999 represent modal lengths).

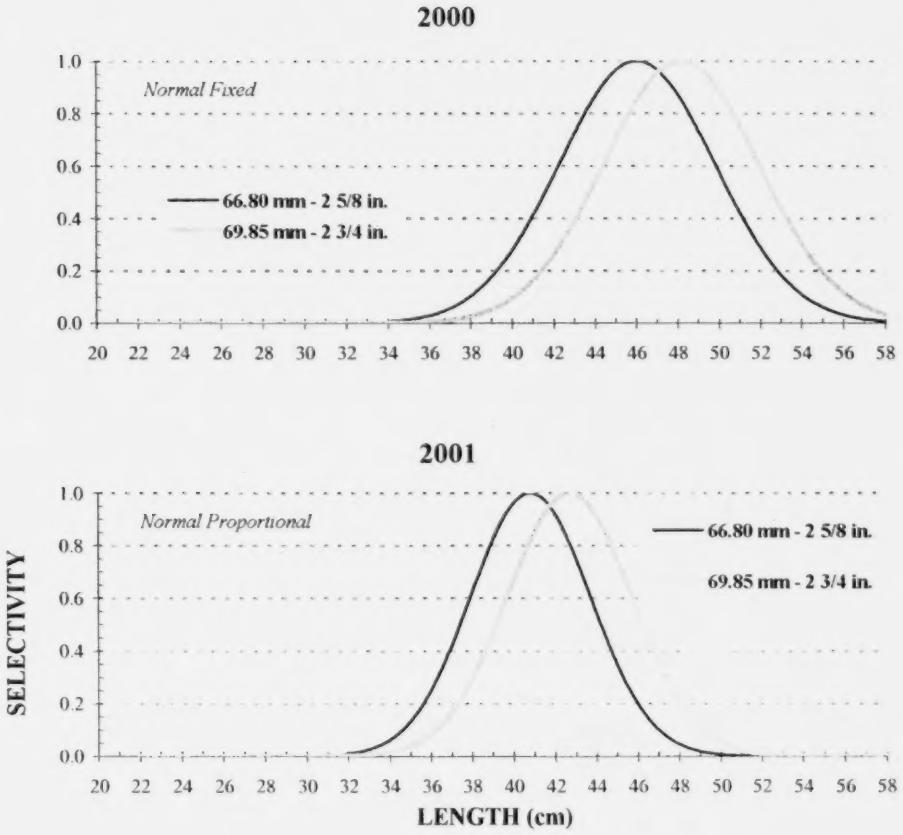

Figure 4. (Continued).

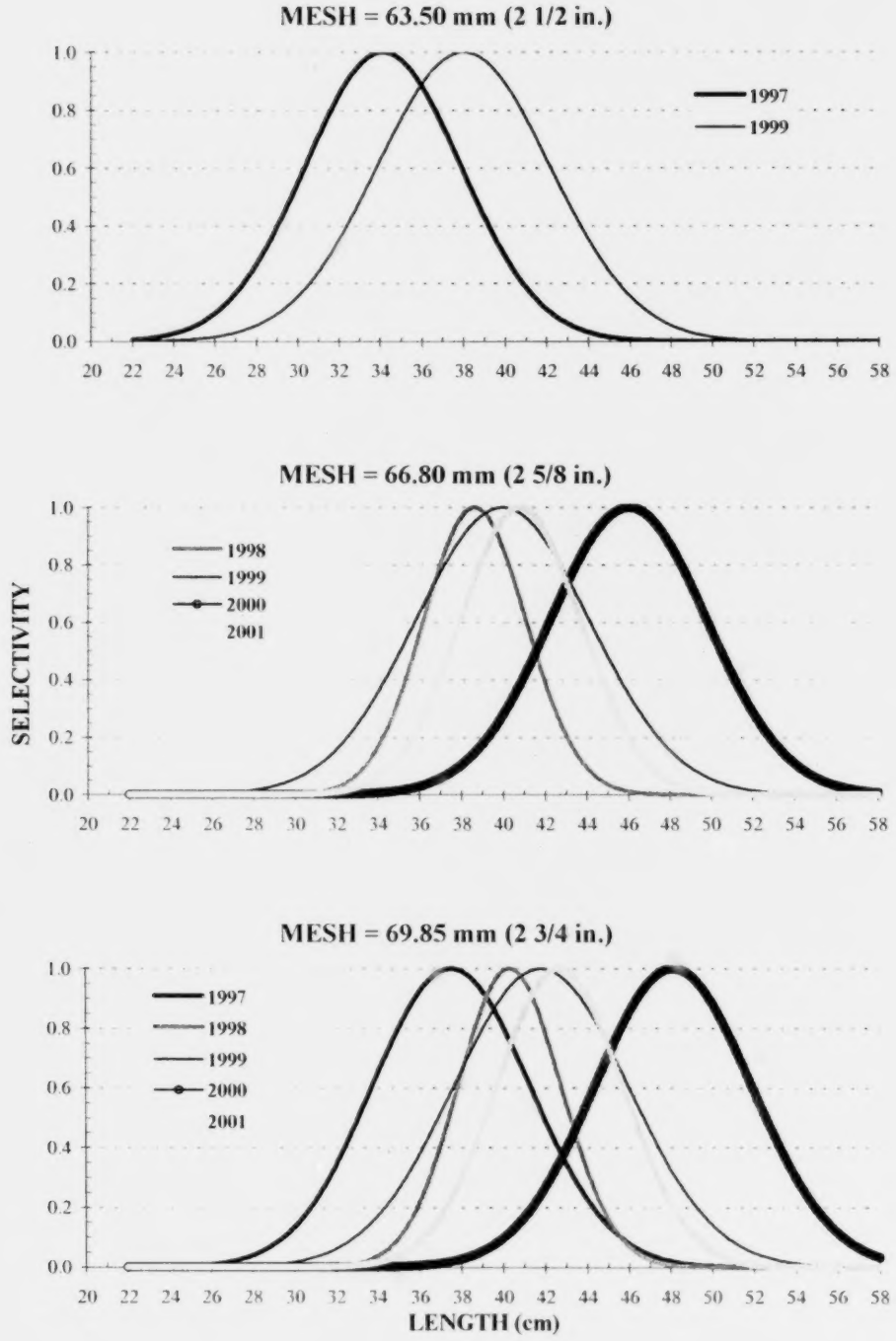

Figure 5. Annual selectivity curves presented by mesh size (mm-in.) for Newfoundland west coast Atlantic herring for the 1997-2001 period.

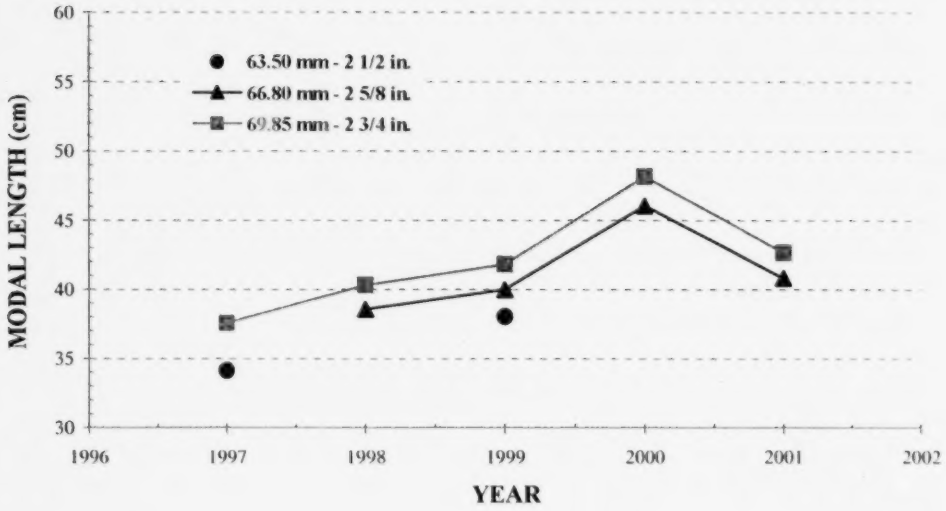

Figure 6. Annual changes in the fish modal length (cm) of the selectivity curves for Newfoundland west coast Atlantic herring.

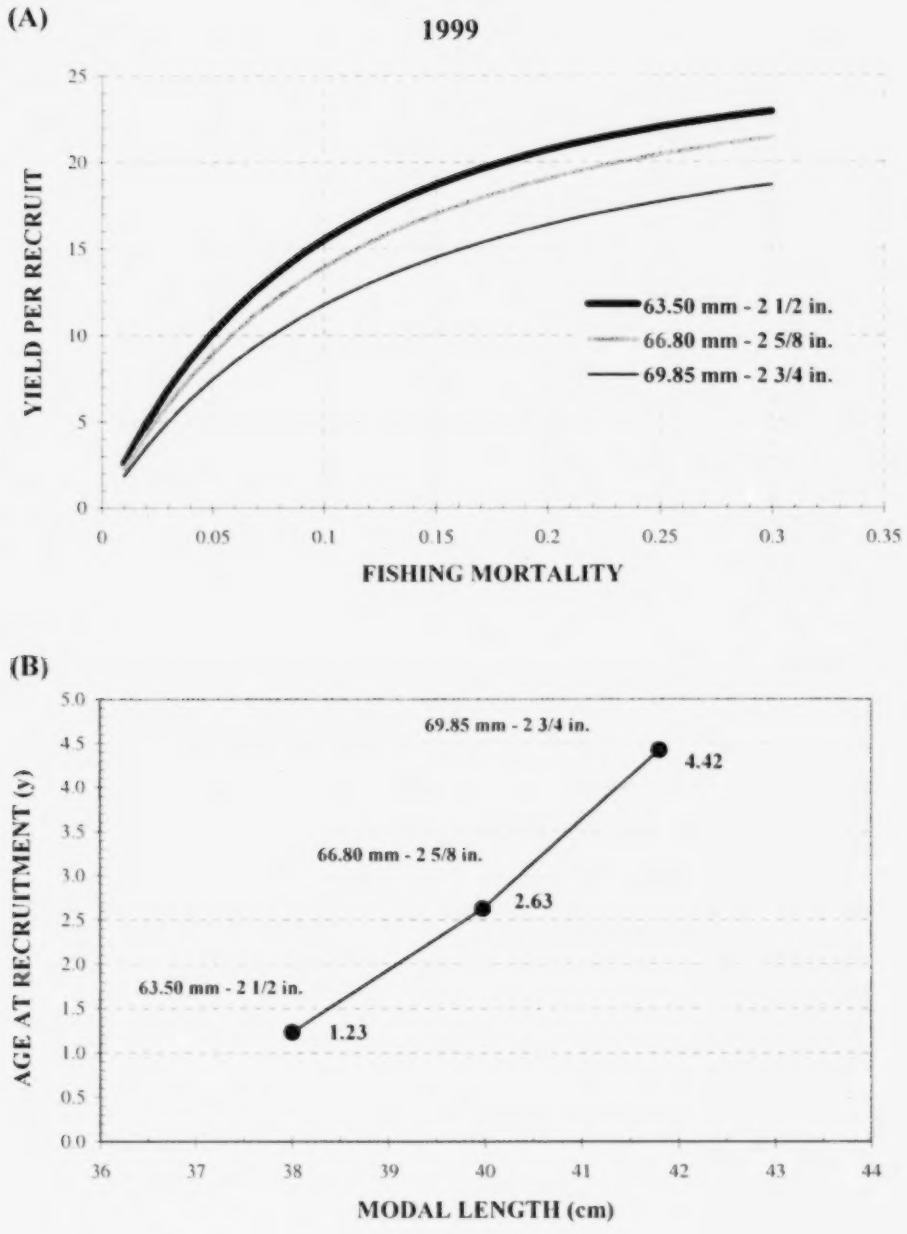

Figure 7. Beverton and Holt yield per recruit model calculated with the 1999 data (A), and the relationship between modal length and the average age at recruitment for herring in the gillnet fishery (B).

Appendix 1. Models tested to calculate gillnet selectivity of Newfoundland west coast Atlantic herring for the 1997-2001 period.

MODEL	SELECTIVITY CURVE*
Normal (proportional spread)	$\exp\left(-\frac{(L - k_1 \bullet m_j)^2}{2k_2 \bullet m_j^{\,2}} \right)$
Normal (fixed spread)	$\exp\left(-\frac{(L - k \bullet m_j)^2}{2s^2} \right)$
Gamma	$\left(\frac{L}{(a-1) \bullet k \bullet m_j} \right)^{a-1} \exp\left(a - 1 - \frac{L}{k \bullet m_j} \right)$
Lognormal	$\frac{1}{L} \exp\left(u_1 + \log\left(\frac{m_j}{m_1}\right) - \frac{s^2}{2} - \frac{\left(\log(L) - u_1 - \log\left(\frac{m_j}{m_1}\right)\right)^2}{2s^2} \right)$

* See Table 3 for the values of the model parameters. L = length and m_j = mesh size.

Appendix 2. Descriptive statistics for each length frequency distribution used in the Newfoundland west coast Atlantic herring selectivity study.

MESH SIZE (mm - in.)	YEAR	N	MINIMUM (cm)	AVERAGE (cm)	MAXIMUM (cm)	STANDARD DEVIATION
63.50 mm - 2 1/2 in.	1997	9 871	29	34.142	40	1.985
	1999	9 880	28	33.625	41	2.826
66.80 mm - 2 5/8 in.	1998	7 744	31	34.906	41	1.914
	1999	4 926	24	34.165	42	3.010
	2000	13 804	26	33.944	43	2.873
	2001	13 882	29	33.687	41	1.901
69.85 mm - 2 3/4 in.	1997	7 400	30	35.151	41	2.067
	1998	2 461	32	36.117	42	2.138
	1999	3 122	29	35.454	41	2.079
	2000	2 176	30	35.148	42	2.662
	2001	4 590	29	34.158	40	2.294
TOTAL	1997	17 271	29	34.574	41	2.081
	1998	10 205	31	35.198	42	2.037
	1999	17 928	24	34.092	42	2.844
	2000	15 980	26	34.108	43	2.875
	2001	18 472	29	33.804	41	2.016